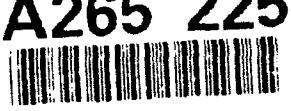

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Reference Dosimetry for the 1992 NATO Battlefield Dosimetry Intercomparison at the Army Pulse Radiation Facility

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Reference Dosimetry for the 1992 NATO Battlefield Dosimetry Intercomparison at the Army Pulse Radiation Facility

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Introduction

A NATO Dosimetry Study was performed from 23 March to 3 April 1992 at the Army Pulse Radiation Facility (APRF), Aberdeen Proving Grounds, Aberdeen, Maryland. This study was designed to determine the accuracy of battlefield dosimeters in a simulated tactical environment, and to compare the different NATO dosimeters in simple, well-defined radiation fields. Dosimeters were irradiated in four radiation fields: in free air (FIA) and on the surface of polyethylene phantoms by the APRF reactor with the core bare and with the core shielded by a converter shield.

Measurements to provide reference dosimetry for the NATO Dosimetry Study were made the week before and the week following the above dates and also during the second week of the battlefield dosimeter comparisons. Reference dosimetry for the NATO Dosimetry Study reactor irradiations was performed by three dosimetry groups.

1. Etablissement Technique Central de l'Armement (ETCA), Arcueil-Cedex, France

2. Armed Forces Radiobiology Research Institute (AFRRI), Bethesda, Maryland, USA

3. Army Pulse Radiation Facility (APRF), Aberdeen, Maryland, USA

Tissue kerma rates FIA and on the surface of phantoms, normalized to reactor power, were measured using paired ionization chambers, a neptunium fission chamber, diodes, rhodium foils, and aluminum oxide and calcium fluoride thermoluminescent dosimeters. For these measurements, the reactor was operated in the steady-state mode. Monitor sulfur pellets and calcium fluoride thermoluminescent dosimeters were used to establish tissue kerma in the pulsed environment used for the irradiation of the battlefield dosimeters.

This report contains a brief description of the radiation facilities and the measurements, and a comparison to the reference dosimetry data of the 1986 NATO battlefield dosimetry intercomparison.

Radiation Fields

The APRF "fast burst" reactor is a bare critical assembly that may be operated at power levels up to 10 kW and at super-prompt criticality to produce pulses with microsecond durations (1-3). For these studies, the reactor was operated inside the reactor silo with the center 2 m above the floor. All dosimetry measurements were made 1.65 m from

the core center and 2 m above the floor (see Figures 1 and 2). The converter shield, when used, was placed in front of the reactor core to better approximate the neutron spectrum 1 km down-range of a nuclear blast. The shield, 12.7 cm thick and 46 cm high, was constructed of polyethylene loaded with cadmium oxide (5% by weight).

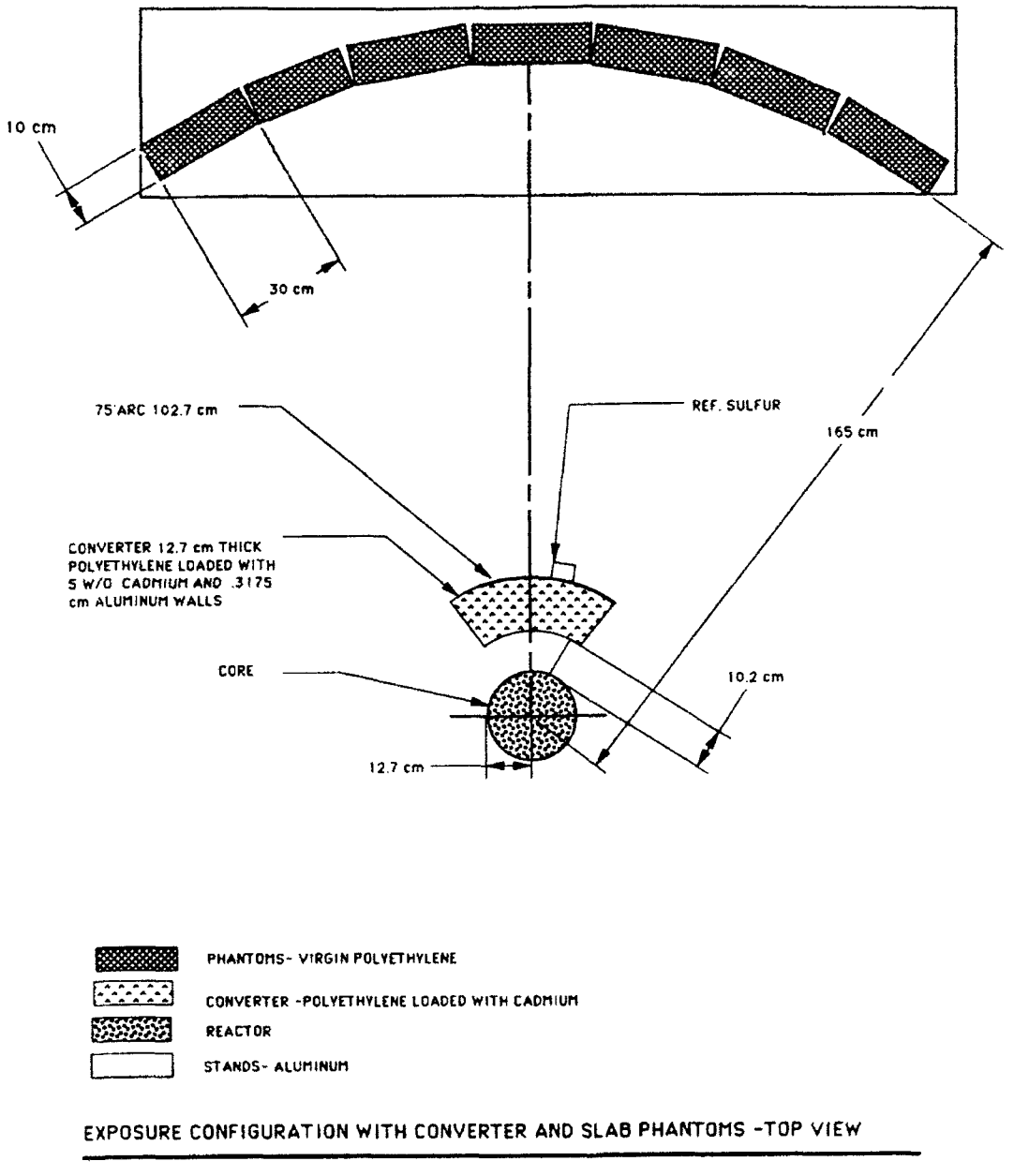
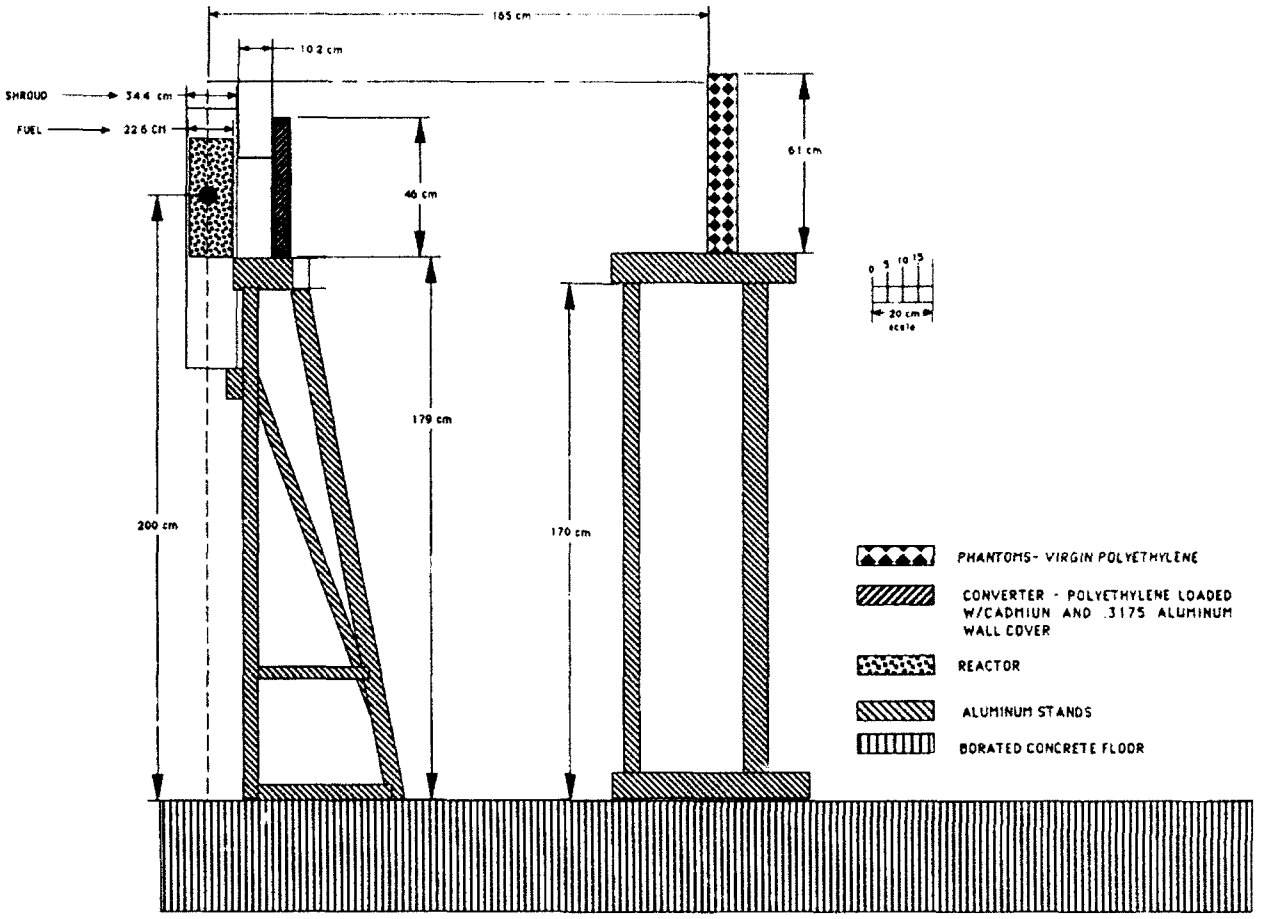


Figure 1. Top-view diagram of irradiation configuration showing the reactor core, the converter shield, and the polyethylene slab phantoms.



EXPOSURE CONFIGURATION WITH CONVERTER AND SLAB PHANTOMS- SIDE VIEW

Figure 2. Side-view diagram of irradiation configuration showing the reactor core with the converter shield and the polyethylene slab phantoms mounted on aluminum stands.

Spectral data for the unshielded APRF configuration were given in a previous technical report (4). Spectral data behind the converter shield are not available, but the qualitative effects of the shield were to reduce the neutron component of the tissue kerma in free air from 92% to 43%, and to produce a harder (more energetic) neutron spectrum. (Neutrons are absorbed by the hydrogenous material, decreasing the fast neutron flux and increasing the gamma-ray flux from hydrogen and cadmium capture reactions. Cadmium absorbs thermal and low-energy neutrons.)

For the irradiations made in free air, the dosimeters were mounted on a thin aluminum screen (see Figure 3) placed along a circular arc located at 1.65 m from the core centerline. When the phantoms were used, the screen was removed and the phantoms (polyethylene blocks 61 cm high, 30 cm wide, and 10 cm thick) were placed along this

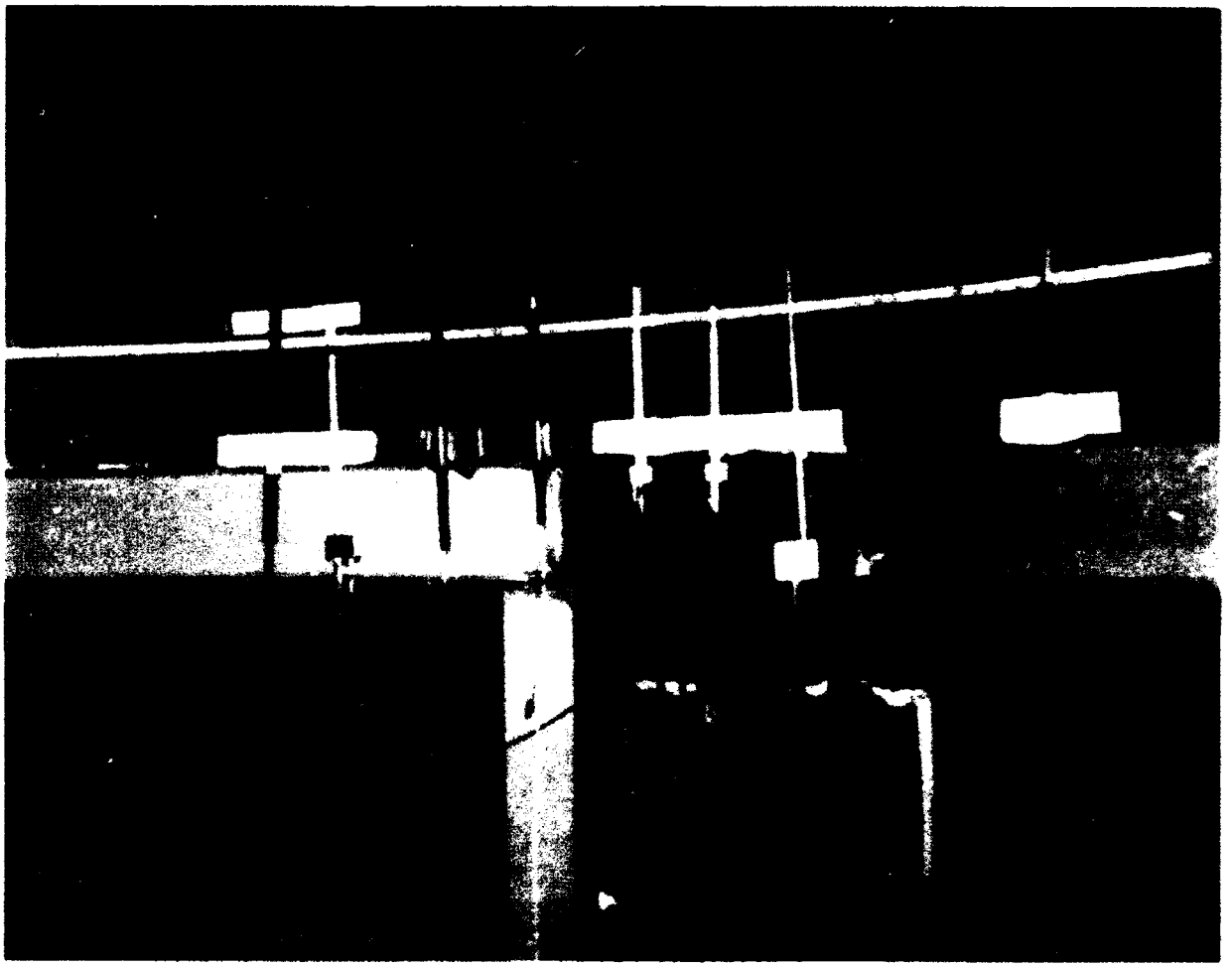


Figure 3. Ionization chambers mounted on the aluminum screen for measurements in free air.

same arc (see Figure 1). The dosimeters were mounted directly on the front surface of the phantoms (see Figure 4). The aluminum screen, the phantoms, and the converter shield were supported by aluminum stands (see Figure 2).

Figure 4. Ionization chambers, the fission chambers, and sulfur pellets mounted on the front surface of the polyethylene slab phantoms.

Measurements

The reactor reference dosimetry was performed with the reactor operated in the steady-state mode and was based on measurements made using a variety of dosimeters.

1. ETCA
   (a) Tissue-equivalent and magnesium-argon paired ionization chambers (TE-Mg IC)
   (b) Tissue-equivalent and aluminum-argon paired ionization chambers (TE-Al IC)
   (c) Tissue-equivalent and teflon-carbon dioxide paired ionization chambers (TE-C IC)
   (d) Neptunium fission chamber (Np FC)
   (e) Silicon diodes
   (f) Rhodium foils
   (g) Aluminum oxide thermoluminescent dosimeters (Al_2O_3 TLD)

2. AFRRI
   (a) Tissue-equivalent and magnesium-argon paired ionization chambers (TE-Mg IC)

3. APRF
   (a) Tissue-equivalent and magnesium-argon paired ionization chambers (TE-Mg IC)
   (b) Calcium fluoride thermoluminescent dosimeters (CaF TLD)

The measurement techniques applied for these dosimeters have been described in other reports (5-12). The measurement results obtained with these dosimeters were transferred to the pulsed environment through the use of sulfur monitor pellets and calcium fluoride TLDs.

Results

The results of the reference dosimetry measurements made in free air with the bare core are shown in Table 1. For this table and all subsequent tables the average total kerma and the average percent neutron kerma are calculated from the average neutron and gamma-ray kermas. The total kerma and percent neutron kerma calculated from the ionization chambers are presented for information. This configuration produced the radiation field with the largest component of neutron kerma, an average of 92%. It is notable that the variety of neutron dosimeters listed have a standard deviation (SD) of only 1%. The gamma-ray kermas, on the other hand, have a 13% SD, due mostly to a low (14.7) and a high (22.1) measurement. It is generally acknowledged that it is difficult to reliably measure a small gamma-ray component in a mixed neutron and gamma-ray field.

Table 1. Reference dosimetry measurements made in free air with a bare reactor core. All tissue kermas in mGy/(kW min). Note that the average total kerma and the average percent neutron kerma are calculated from the average neutron and gamma-ray kermas.

Group	Dosimeter type	Neutron kerma	Gamma-ray kerma	Total kerma	% neutron kerma
ETCA	TE-Mg IC	204	17.8	222	92
	TE-Al IC	204	17.3	221	92
	TE-C IC	207	14.7	222	93
	Np FC	204	--	--	--
	Diode	202	--	--	--
	Rh foil	203	--	--	--
	Al_2O_3 TLD	--	17.0	--	--
AFRRI	TE-Mg IC	205	16.1	221	93
APRF	TE-Mg IC	205	17.6	223	92
	CaF TLD	--	22.1	--	--
	Average	204 +/- 1.5 (1%)	17.5 +/- 2.3 (13%)	222	92

Table 2 shows the results obtained when the dosimeters were mounted directly on the front surface of the phantoms and irradiated with the bare core. The effect of the phantoms is to increase by 5% the neutron kerma due to backscattering, and to increase the gamma-ray kerma by 2.6 times due to neutron-energy moderation and neutron capture by hydrogen in the phantoms. The net effect is to reduce the neutron kerma to 83% of the total kerma. For the larger component of gamma-rays now present, the measurements gave an SD=5%.

Table 2. Reference dosimetry measurements made on the surface of the phantoms with a bare reactor core. All tissue kermas in mGy/(kW min). Note that the average total kermas and average percent neutron kerma are calculated from the average neutron and gamma-ray kermas.

Group	Dosimeter type	Neutron kerma	Gamma-ray kerma	Total kerma	% neutron kerma
ETCA	TE-Mg IC	214	44.4	258	83
	TE-Al IC	212	46.5	258	82
	TE-C IC	210	47.5	258	82
	Np FC	217	--	--	--
AFRRI	TE-Mg IC	218	41.4	259	84
APRF	TE-Mg IC	215	45.1	260	83
	CaF TLD	--	46.8	--	--
	Average	214 +/- 3.0 (1%)	45.3 +/- 2.2 (5%)	259	83

The reference dosimetry measurements made in free air with the converter shield interposed between the core and the dosimeters are shown in Table 3. The introduction of this shield reduces the neutron kerma to only 18% of its former value and increases the gamma-ray kerma 2.7 times. The neutron kerma component is thus reduced to 43%. Even though fewer neutron dosimeters were used for these measurements, for the neutron kerma the SD is now increased to 6%. The gamma-ray kermas, however, now have SD=1%.

Table 3. Reference dosimetry measurements made in free air with the converter shield. All tissue kermas in mGy/(kW min). Note that the average total kerma and average percent neutron kerma are calculated from the average neutron and gamma-ray kermas.

Group	Dosimeter type	Neutron kerma	Gamma-ray kerma	Total kerma	% neutron kerma
ETCA	TE-Mg IC	35.1	46.7	81.8	43
	TE-Al IC	34.6	47.4	82.0	42
	TE-C IC	34.3	47.7	82.0	42
	Np FC	33.9	--	--	--
AFRRI	TE-Mg IC	36.9	47.5	84.4	44
APRF	TE-Mg IC	39.3	46.0	85.3	46
	CaF TLD	--	46.8	--	--
	Average	35.7 +/- 2.1 (6%)	47.0 +/- 0.6 (1%)	82.7	43

When measurements are made on the surface of the phantoms with the converter shield in place, the results shown in Table 4 are obtained. Compared to Table 3, there appears to be little effect due to neutron backscattering. The gamma-ray kerma, however, is 18% larger than the FIA measurements due to neutron-energy moderation and neutron capture by hydrogen. This configuration produces the lowest component of neutron kerma, 39%.

Table 4. Reference dosimetry measurements made on the surface of the phantoms with the converter shield. All tissue kermas in mGy/(kW min). Note that the average total kerma and the average percent neutron kerma are calculated from the average neutron and gamma-ray kermas.

Group	Dosimeter type	Neutron kerma	Gamma-ray kerma	Total kerma	% neutron kerma
ETCA	TE-Mg IC	35.8	55.6	91.4	39
	TE-Al IC	34.8	56.6	91.4	38
	TE-C IC	33.7	57.6	91.3	37
	Np FC	33.3	--	--	--
	Diode	33.0	--	--	--
	Al_2O_3 TLD	--	52.0	--	--
AFRRI	TE-Mg IC	37.8	56.5	94.3	40
APRF	TE-Mg IC	39.0	56.4	95.4	41
	CaF TLD	--	52.4	--	--
	Average	35.3 +/- 2.3 (7%)	55.3 +/- 2.1 (4%)	90.6	39

Uncertainties

The precision of the ionization chamber measurements is generally better than 1%. The absolute accuracy of the paired ionization chamber method is considered to be around 5%-8%. When a component of the radiation field is small relative to the total kerma, however, the accuracy for determining this component may be considerably poorer.

Manufacturer's specifications for the CaF TLDs gives a precision of +/- 6.5% for a group of 5000 chips. Measurements at APRF using 30 chips have verified this value. The CaF TLDs are calibrated with a Co-60 gamma-ray cell whose calibration is traceable to the National Institute of Standards and Technology. Groups of six TLDs are irradiated with doses ranging from 1 to 5000 Gy and the light output measured with a Harshaw 4000 reader is plotted versus dose to establish a calibration curve. Although the calibration of the gamma-ray cell is accurate to +/- 3%, their accuracy for the reference dosimetry measurements depends on how well the calibrator spectrum compares to the gamma-ray spectrum produced by the reactor. Their accuracy for the gamma rays from the reactor is estimated to be +/- 10%.

Measurements performed at AFRRI by J. H. Musk indicate a reproducibility within +/- 4% for Al_2O_3 TLDs (13).

Comparison to Previous Data

The results of the 1986 NATO reference dosimetry measurements were presented in a previous technical report (4). At that time, no measurements were made with the bare reactor core. Table 5 compares the 1986 ionization chamber results obtained using the converter shield with the 1992 (present) results for the configuration when the dosimeters were in tree air. The difference between the two data sets is less than 2%.

Table 5. Comparison of 1986 and 1992 reference dosimetry for measurements made in free air using the converter shield. All tissue kermas in mGy/(kW min).

Data set	Neutron kerma	Gamma-ray kerma	Total kerma	% neutron kerma
1986	35.1	46.5	81.5	43
1992	35.7	47.0	82.7	43
1992/1986	1.017	1.011	1.015	--

When the dosimeters were mounted on the surface of the phantoms and the converter shield was used, the comparison of the 1986 and 1992 data sets is as shown in Table 6. It can be seen that the present data for neutron kerma are, on average, about 6% lower than the earlier data. Examination of Table 4 shows that this is due to the low values of neutron kerma obtained with the five ETCA dosimeters. The two values of neutron kerma obtained by the AFRRI and APRF ionization chambers are actually a little higher than the 1986 value. It is worth noting that ETCA did not participate in the 1986 reference dosimetry measurements.

Table 6. Comparison of 1986 and 1992 reference dosimetry for measurements made on the phantoms using the converter shield. All tissue kermas in mGy/(kW min).

Data set	Neutron kerma	Gamma-ray kerma	Total kerma	% neutron kerma
1986	37.6	54.9	92.5	41
1992	35.3	55.3	90.6	39
1992/1986	0.939	1.007	0.979	--

Conclusion

The reference dosimetry measurements described in this report serve to provide an absolute calibration of the tissue kerma rates in the radiation fields used for the 1992 NATO battlefield dosimeter intercomparison. Although a greater variety of dosimeters were used for these measurements than in the 1986 study, the eight dosimetry systems gave results which agreed well among themselves as well as with past values. Thus the kermas derived from these results can be used confidently to evaluate the accuracy of the NATO battlefield dosimeters intercompared in 1992.

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